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Investigation of the Responses of the General Circulation at 700 mb To Solar-Geomagnetic Disturbance

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ABSTRACT

The northern hemisphere 700 mb contour heights from 20 N to 70 N for the period 1947-1970 are studied in conjunction with 272 key days, where the daily increase of the Ci index equals or exceeds 1.0. The superposed epoch method is applied from 33 days before to 66 days after the key day for a variety of zonal and meridional indices. It is shown that the 700 mb height difference between 20 N and 55 N increases significantly in winter 4 days following geomagnetic disturbance (in summer a less prominent but statistically significant increase is found 2 days earlier). The effect is most clear in winter in the quadrant 90-175 W and corresponds to a 7% increase in the mean geostrophic westerly flow. The statistical significance of the results is established by applying Student's t-test to the difference of each daily mean from the continuum. Synoptic analyses of the departures of the mean 700 mb contour heights from seasonal climatology following geomagnetic disturbance reveal that the effect proceeds with the growth and development of large negative centers in the latitude belt 40-60 N and smaller positive departures at lower latitudes.

1. Introduction

A number of studies (Mustel et al., 1965; Mustel, 1966; Kubyshkin, 1965,1966) claim to have discovered surface pressure responses to solar-geomagnetic disturbances. On the other hand, studies by Stolov and Spar (1968) and Stolov and Shapiro (1969) failed to substantiate the reported claims. More recent studies by Sarukhanyan and Smirnov (1970) and Mustel (1970) indicate that the zonal character of the atmospheric circulation is disrupted and that meridional processes are enhanced during disturbed periods. However, Stolov and Shapiro (1971) find no evidence for this claim.

In earlier work, Shapiro (1956,1959,1972) working with sea-level pressure data found significantly high persistence during the first week after large increases in geomagnetic activity along with an increase in the average north-south pressure gradient. A current study by Roberts and Olson (1973) confirms their earlier result connecting geomagnetic activity with a subsequent deepening of 300 mb troughs.

Encouraged by these positive results, we have been stimulated to extend our previous investigation. In this latest study, the strong seasonal trend in the 700 mb heights introduced by ordinary meteorological factors is removed as a possible obscuration in the detection of real general circulation changes following solar-geomagnetic activity. Apparently just such an approach was necessary.

2. Data

The meteorological data consist of 1200 UT sea-level pressures

and 700 mb heights from 20 N to 70 N for the period 1 January 1947 to 31 December 1970. The data are available at 5° latitude intervals and 10° longitude intervals in a diamond-shaped grid. As measures of solar-geomagnetic disturbance, we selected in the preliminary investigation (Stolov and Shapiro, 1971):

1. The 41 chromospheric flares (1956-1960) producing geomagnetic disturbance used by Mustel et al. (1965).
2. The 39 chromospheric flares (1961-1967) producing geomagnetic disturbance used by Stolov and Shapiro (1969).
3. The 39 large isolated geomagnetic disturbances (1947-1961) selected by Mustel (1968).
4. The 63 large, less-isolated geomagnetic disturbances (1947-1969) selected by Mustel (1968,1970).
5. The 272 events (1947-1970) where the daily increase of the International Magnetic Character Figure (Ci) equals or exceeds 1.0 used by Shapiro (1972) and compared with Kp in Shapiro (1973).

It is altogether clear that all five lists are intimately related. The solar key days in lists 1 and 2 tend to precede the geomagnetic key days by one to two days. The geomagnetic key days in list 5 include most of the key days in lists 3 and 4 as well as a number of moderate disturbances. The objective selection criterion of list 5 is an obvious advantage.

3. Preliminary Investigation Yielding Negative Results

The method of analysis used to test for possible meteorological responses was the well-known superposed epoch analysis. A separate

analysis was performed with each of the five groups of key days both at sea level and 700 mb for each of the parameters listed:

a. polar easterlies $(\bar{P}_{70\ N} - \bar{P}_{55\ N})$

b. middle latitude westerlies $(\bar{P}_{35\ N} - \bar{P}_{55\ N})$

c. subtropical easterlies $(\bar{P}_{35\ N} - \bar{P}_{20\ N})$

d. four meridional indices $(\hat{P}_o - \hat{P}_{90};\ \hat{P}_{90} - \hat{P}_{180};\ \hat{P}_{180} - \hat{P}_{270};\ \hat{P}_{270} - \hat{P}_o)$

e. standard deviation of pressure around each latitude circle (20 N-70 N) in intervals of 5 deg.

f. standard deviation of pressure within 12 sectors defined by latitudes 20 N, 35 N, 55 N and 70 N and longitudes 0,90,180, and 270,

where $\bar{P}$ is the average around a latitude circle and $\hat{P}$ is the average along a meridian between 20 N and 70 N. With five groups of key days and 30 parameters at each of two levels, 300 separate superposed epoch analyses were obtained. In each analysis, the parameter was examined from 33 days before to 66 days after the key day. Student's t-test was applied to the difference of each daily mean from the population mean in order to establish the 5% confidence limits. The results revealed approximately the chance expectancy with no special preference after or before the key day. Concentrating on the Ci key days, these were segregated into four seasons and superposed epoch analyses were performed for each of the 30 parameters for both levels for each of the four new sets of key days. Although these superposed epoch results were also negative, the seasonal trends in the parameters over the 100 day periods were so overwhelming as to suggest that any solar-terrestrial effects that might be present

would likely be obscured. With this in mind, the current investigation was undertaken.

4. Current Investigation - Superposed Epoch Analysis

In the present study we have confined our attention to the Ci key days and to the 700 mb heights. Our previous experience indicates that this approach is clearly the most objective and likely the most promising provided that the problem of seasonal trend obscuration can be handled. Figure 1 shows the results of a number of superposed epoch analyses performed on the daily differences of the mean zonal 700 mb contour heights around latitudes 20 and 55 N for the period 1947-1970. The results are shown separately for the four seasons (winter: December-February; spring:March-May; summer: June-August; fall: September-November). The abscissa of Figure 1 extends from 33 days before the key days to 66 days after. Each of these days bears a constant phase difference from the key day and, where necessary for clarity, will be referred to as phase-days. The reason for performing the analyses over a hundred day range was to permit comparison of the events immediately after the key day with a large sample of events far removed from the key day and, therefore, presumably, not influenced (on the average) by any possible solar-geomagnetic event. Another purpose, which will become evident later, was to permit an additional test of significance. The data of Figure 1 are presented in terms of the Student's t-test corresponding to the departure of each phase-day mean from its continuun value. It is necessary to analyze the phase-day means as departures from a continuum, rather than departures from the population mean of 100 n values, because the seasonal differences between the extreme ends of

the curves would otherwise completely dominate the results. (n is the number of key days used for each season). The continuum, for any particular phase-day, is defined as the mean of the 21 phase-day means centered on the particular phase day.

Positive values of t indicate that the phase-day mean exceeds the continuum value and implies a greater than "average" contour height difference (20 N minus 55 N) and, therefore, to the extent that the mid-latitude 700 mb winds are geostrophic, implies a greater than average wind from west to east. Magnitudes of t of 2.0 or more indicate that the chance expectancy of such a departure of the phase-day mean from the continuum is 5% or less. It can be noticed that there are only two days where such values of t are obtained - days 4 and 5 of the winter curve. This frequency is much less than that expected by chance alone and is due in part to the method of analysis. The phase-day means are highly persistent from one day to the next. Thus, a large departure on some one phase-day implies similarly large departures on at least the day before and the day after. Since these three phase-day values are included in the continuum value for the phase day in questions, they would tend to exaggerate the continuum value and thus depress the magnitude of Student's t. It is estimated that if the phase-day in question and the day before and after were eliminated from the computation of the continuum, it would increase the magnitude of those values of t which are already large (say ≥ 1.0) by about 15 to 20%. This would have the effect of elevating the magnitudes of these t-values but nevertheless no more than three additional values would thus be

elevated to around 2.0.

The principal reason for the very small number of t-values with large magnitude is due to the fact that the sample of calender days on any phase-day ranges over the three months of the season. In addition to containing the usual sampling fluctuations, the phase-day means contain an appreciable variation from the pronounced seasonal differences in the mean contour height gradient. Thus, the estimate of the standard deviation appropriate for the phase-day mean is appreciably greater than it would be if the seasonal variation were first removed from the data. It is estimated that the standard deviations being used in the computation of Student's t are about twice as large as they should be. This state of affairs introduces no real difficulty as long as we do not expect to find 20 phase days in Figure 1 where the magnitude of t equals or exceeds 2.0. In fact, we could determine from the sample of 400 t-values, an approximate magnitude for the 5% significance level. We find that 5% of the 400 t-values have a magnitude equal to or greater than 1.0. A reasonable, though unsophisticated, approach would be merely to use a magnitude of 1.0 as indicative of significance at the 5% level.

However, we shall use a somewhat different approach and avoid the whole question of the relative magnitude of t. We shall treat each set of 100 t-values as a quasi-random selection from a population whose mean and standard deviation we shall assume to be the same as the mean and standard deviation of the given 100 t-values. For example, for the winter set, the mean t is nearly zero (0.05) and the standard deviation around this mean is 0.62. Thus, the value of Student's t on day 4 (2.27) is

nearly 4 standard deviations above the mean. The mean and standard deviation for each seasonal set of 100 t-values is given in Table 1.

TABLE 1

MEAN AND STANDARD DEVIATION OF EACH SEASONAL SET OF 100 t-VALUES REPRESENTED IN FIGURE 1

Season	Mean	Standard Deviation
Winter	0.05	0.62
Spring	-0.02	0.50
Summer	-0.11	0.57
Fall	0.04	0.39

The only phase days in Figure 1 where the t-value departs from the mean of the set by at least three standard deviations are days 4 and 5 in the winter and days 1 and 2 in the summer. These positive departures indicate a significant increase in the zonal index or mean zonal geostrophic flow in middle latitudes. These results are consistent with those reported by Shapiro (1959), who found that the increased persistence during the first week after incresases of Ci was largely due to increased zonal flow. The increase in zonal flow was most pronounced over the North American region (60-120 W, 30-60 N) but was also manifest over the European region (30 E-30 W, 35-65 N).

In order to determine whether the increased zonal flow which occurs shortly after the key day in winter and summer is uniformly distributed around the hemisphere or is restricted to certain longitude regions, the data

for these two seasons were examined separately for the four quadrants 0-85 W, 90-175 W, 180-265 W, 270-355 W. The results are shown in Figure 2. In winter, the increased zonal flow is largely limited to the half hemisphere, 90-265 W, and is most pronounced in the quadrant 90-175 W. In summer, however, the increased zonal flow is more modest but more uniformly distributed around the hemisphere. This difference in behavior cannot, of course, be explained on the basis of these results. However, in terms of consistency, they are in agreement with the results of Roberts and Olson (1973), who find trough intensification in winter over North America following geomagnetic disturbance.

The difference in behavior between winter and summer may be characterized in the following manner. In winter, the average of the t-values for the four quadrants is a maximum on phase-day 4 and in summer on phase-day 2. In both cases, these average values are the largest in the entire range of one hundred phase days for the respective seasons. However, in winter, for both quadrants where the increased zonal flow is most pronounced (90-175 W and 180-265 W), the t-values on phase-day 4 are the largest in the entire range of phase days for the respective quadrants - whereas in summer, in three of the four quadrants, there are larger t-values on days other than phase-day 2.

Since the results of Figure 1 and 2 are given in terms of Student's t, it is of interest, for purposes of orientation, to note the magnitude of the departures of the mean zonal gradients from the continuum values. For example, for the entire hemisphere, the winter continuum value of the mean

height difference of the 700 mb surface between 20 N and 55 N on and around phase-day 4 is 1016 feet which corresponds, roughly, to a geostrophic wind speed of about 7.9 m sec^{-1} for this entire belt. The observed height difference on phase-day 4 is 1046 feet or about 3% greater than the continuum (see Figure 3). This small percent difference is highly significant from a statistical point of view, but amounts to little more than a 0.2 m sec^{-1} increase in mean westerly geostrophic wind. In summer, on phase-day 2, the continuum and observed height differences are 479 feet and 490 feet respectively, corresponding to an increase of mean geostrophic wind from about 3.6 to less than 3.8 m sec^{-1} (see Figure 4). The magnitude of the increase is somewhat greater for the quadrant 90-175 W on phase-day 4 during winter. The appropriate continuum height difference is 998 feet whereas the phase-day 4 difference is 1065 feet, corresponding to an increase of more than 7% or to about 0.6 m sec^{-1} increase in mean geostrophic wind (see Figure 5). This is not a trivial increase in "wind" considering the width of the latitude belt 20-55 N.

5. Current Investigation - Synoptic Analysis

In order to elucidate more specifically the apparent increase of the zonal wind in winter and summer, we undertake a northern hemisphere synoptic analysis of the departures of the 700 mb contour heights from seasonal climatology before and after the disturbed key day. Figures 6 and 7 show the mean 700 mb contour heights (in feet) obtained from all winter

and summer days respectively during the period 1947-1970, establishing the seasonal climatology. Figures 8-12 show the winter synoptic development of the departures of the 700 mb contour heights (in feet) from the winter climatology (bottom curves) as well as in terms of the corresponding Student's t (top curves) for the phase - days - 4, 0, 4, 6, and 8, respectively. For the winter sequence, we note that before and on phase-day 0, there are scattered and alternating centers of positive and negative departures from climatology. Some of these departures, which represent averages over 74 different days during the 24-year period, are relatively large, both in terms of the magnitude of the departures and in terms of Student's t. However, beginning almost immediately after day 0, the departures begin to be organized so that the negative departures tend to be concentrated between latitudes 40 - 60 N and the smaller positive departures tend to move toward lower latitudes. This process reaches its maximum development on phase-day 4 and then begins to decay. On phase-day 4, there is a large depression of contour height centered near 90 W and 55 N. This is situated just west of the trough line located between 60 and 90 W on the winter climatology map (Figure 6). It is perhaps only coincidental that 90 W is near the longitude of most southerly extension of the geomagnetic latitudes and might therefore be where corpuscular radiation penetrates farthest south in the earth's atmosphere. By the time phase-day 8 arrives, the character of the departures of 700 mb contour height from the winter climatology have become rather small and disorganized, and similar in overall character

to the phase-days before day 0. Figures 13-17 show the summer synoptic development of the departures of the 700 mb contour heights (in feet) from summer climatology (bottom curves) as well as in terms of the corresponding Student's t (top curves) for the phase - days - 4, 0, 2, 4, and 6, respectively, so selected because of the more rapid development. On day - 4, there are a number of small isolated centers. Although these centers are mostly negative, there are some positive centers at the higher latitudes. However, on day 0, there is an appreciable growth and organization of these negative centers in the latitude belt 50 - 60 N. This growth reaches its maximum development on phase-day 2 and then decays rapidly. On phase-day 4, there are two sizeable positive centers, interspersed among the negative centers in the middle latitude belt (40 - 60 N). Phase-day 6 with a scattering of small positive and negative cells has a quasi-random appearance.

6. Summary and Conclusions

Firm statistical evidence is presented which strongly suggests the existence of a real relationship between solar-geomagnetic disturbance and the subsequent behavior of the 700 mb contour height difference between 20° N and 55° N. In winter, four days following geomagnetic disturbance, there is a significant increase in the zonal index, or mean zonal geostrophic flow. In summer, a less prominent but statistically significant increase in the zonal index is found two days earlier. The effect is most prominent in winter in the quadrant 90 - 175 W and corresponds to a 7% increase in the mean westerly flow. Synoptic

analyses of the departures of the mean 700 mb contour heights from seasonal climatology following geomagnetic disturbance reveal that the effect proceeds with the growth and development of large negative centers in the latitude belt 40 - 60 N and smaller positive departures at lower latitudes. Although no acceptable physical mechanisms are available to explain the observations, further statistical studies may lead to a better physical understanding and hopefully may contribute one day to weather forecasting.

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Figure Legends

Fig. 1. Daily differences of the mean zonal 700 mb contour heights around latitudes 20 and 55 N shown separately for the four seasons from 33 days before to 66 days after the Ci key days presented in terms of the Student's t-value corresponding to the departure of each phase-day mean from its continuum value.

Fig. 2. Daily differences of the mean 700 mb contour heights along 20 and 55 N for winter and summer, separated into quadrants and presented as in Fig. 1.

Fig. 3. The mean height differences (in feet) of the 700 mb surface between 20 N and 55 N for the entire hemisphere in winter from 33 days before to 66 days after the Ci key days. The 21 day continuum is shown by a dark line. Student's t-values, corresponding to the departures of each phase-day mean from its continuum value, are also shown.

Fig. 4. Same as Fig. 3 but for the entire hemisphere in summer.

Fig. 5. Same as Fig. 3 but for the quadrant 90-175 W in winter.

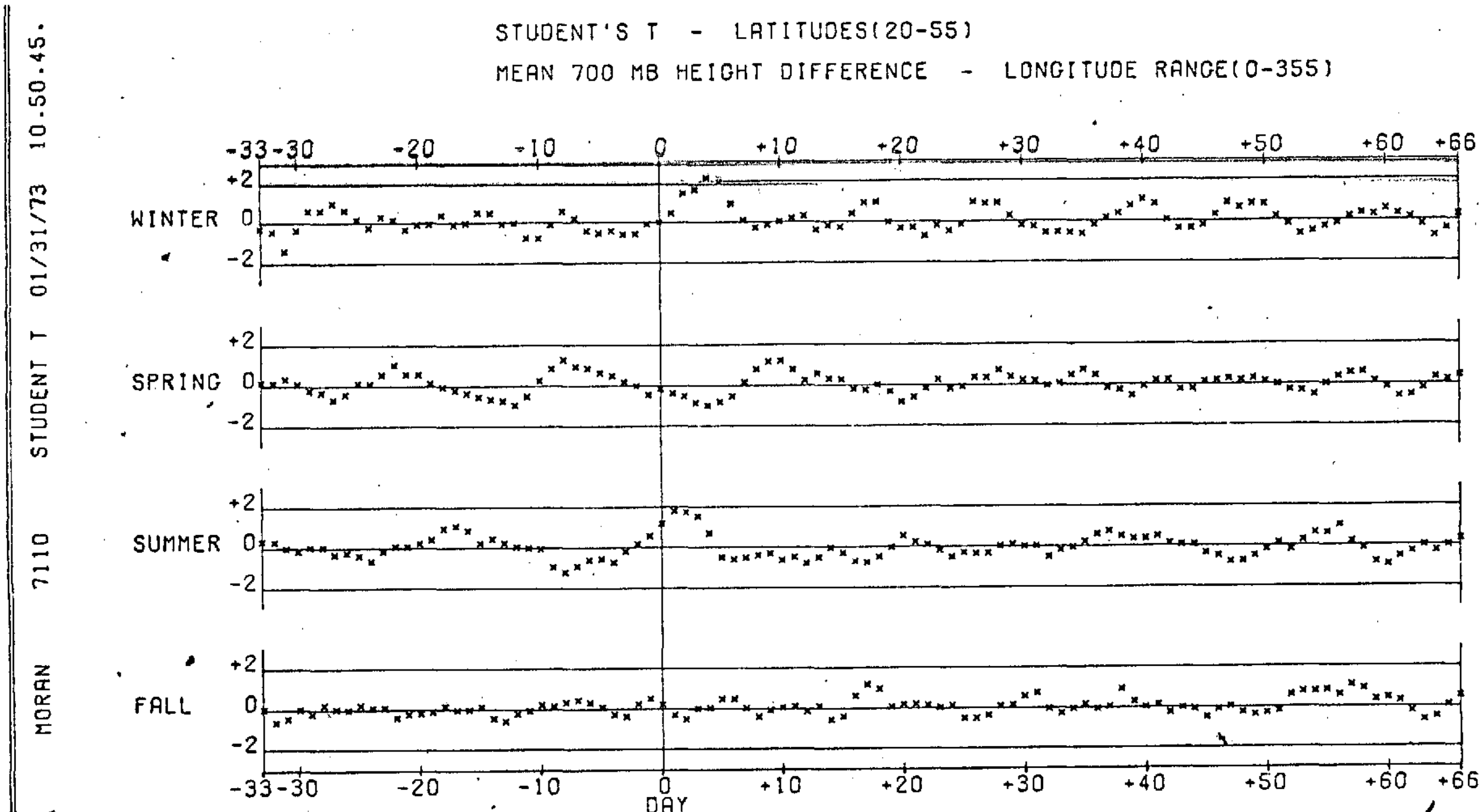
Fig. 6. Mean 700 mb contour heights (in feet) obtained from all winter days during the period 1947-1970 running west from 0° to 360°.

Fig. 7. Mean 700 mb contour heights (in feet) obtained from all summer days during the period 1947-1970 running west from 0° to 360°.

Fig. 8-12. Departures of the 700 mb contour heights (in feet) from winter climatology as well as in terms of the corresponding Student's t for the

phase days -4, 0, 4, 6 and 8 respectively.

Fig. 13-17. Departures of the 700 mb contour heights (in feet) from summer climatology as well as in terms of the corresponding Student's t for the phase-days -4, 0, 2, 4, and 6 respectively.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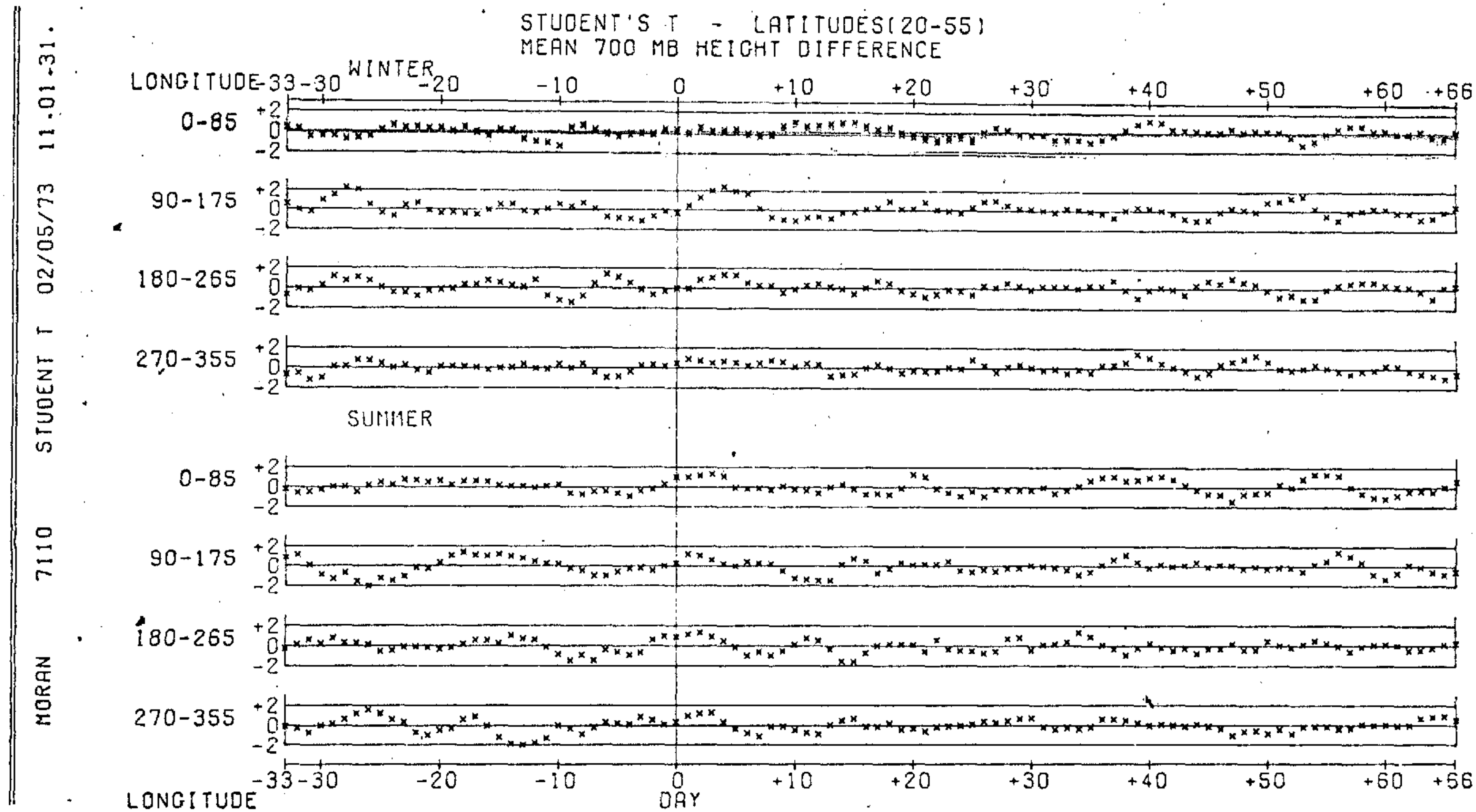
MEAN 700 MB HEIGHT DIFFERENCE - LONGITUDE RANGE(0-355)
MORAN 7110 STUDENT T 01/31/73 10.50.45.
WINTER
SPRING
SUMMER
FALL
+2
0
-2
-33 -30 -20 -10 0 +10 +20 +30 +40 +50 +60 +66
DAY

Fig 1.

Fig. 1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MEAN 700 MB HEIGHT DIFFERENCE
WINTER
SUMMER
LONGITUDE
0-85
90-175
180-265
270-355
DAY
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MORAN 7110 STUDENT T 02/05/73 11.01.31.

Fig. 2

Fig 2

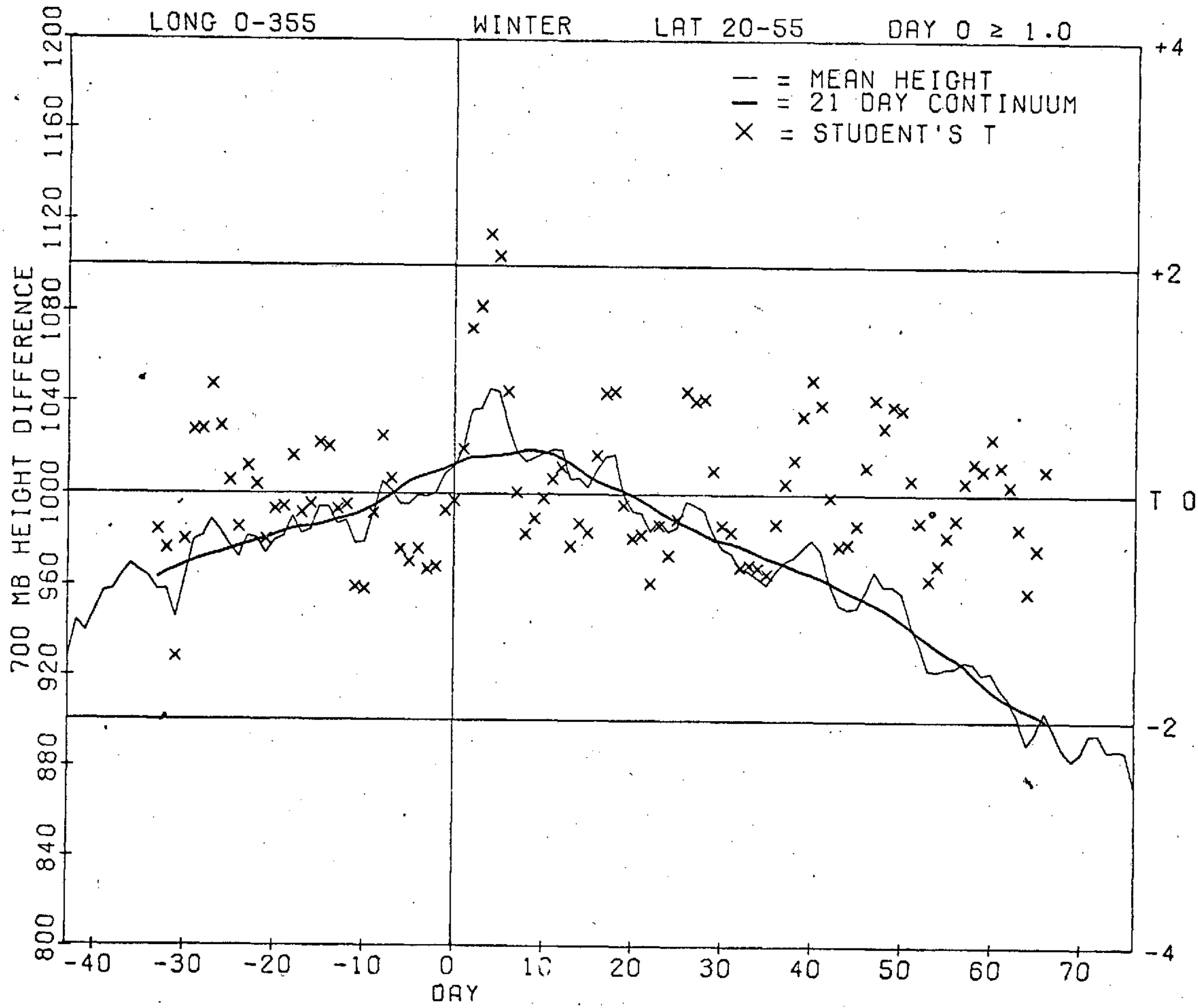
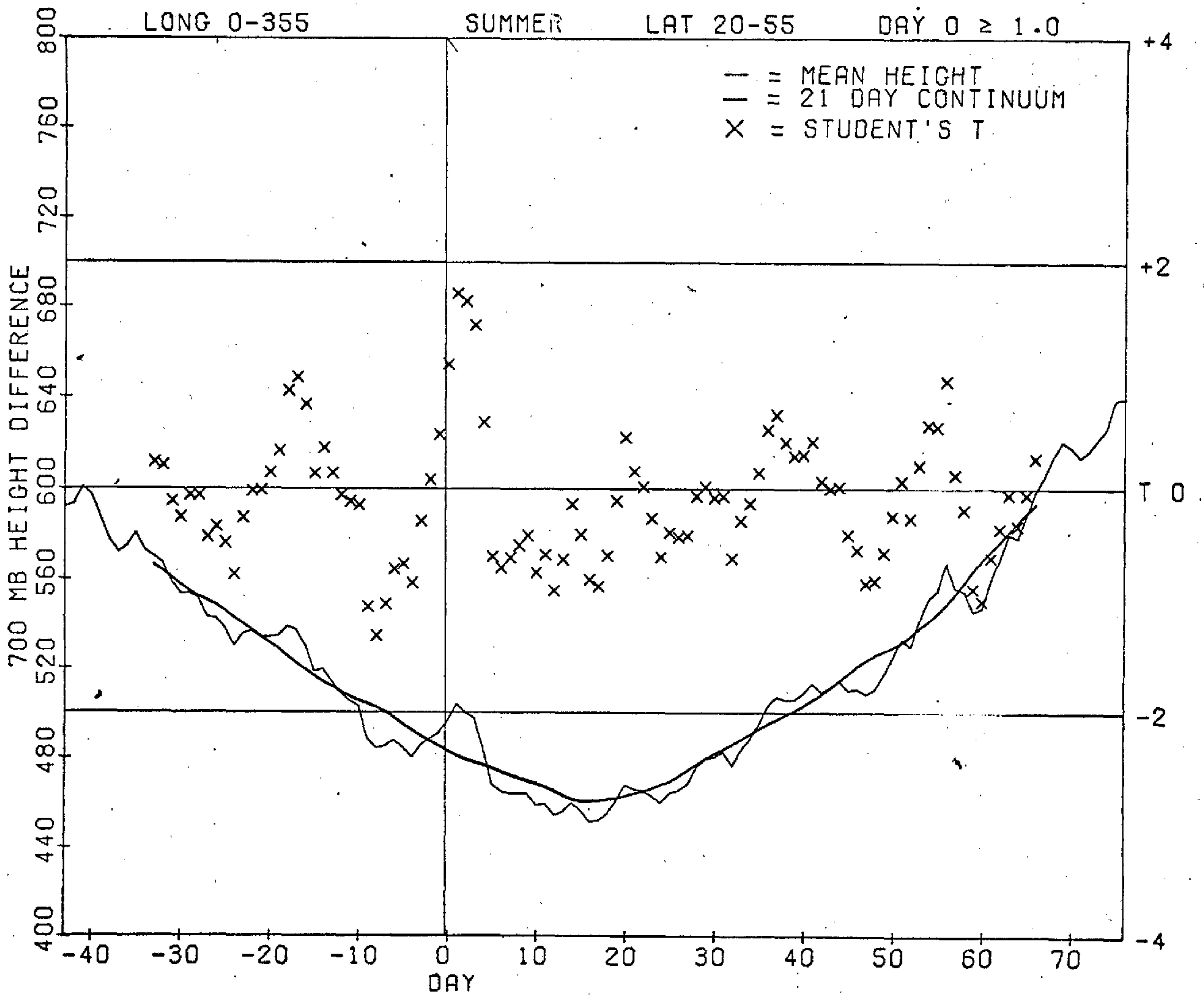

LONG 0-355
WINTER
LAT 20-55
DAY 0 ≥ 1.0
— = MEAN HEIGHT
— = 21 DAY CONTINUUM
X = STUDENT'S T
700 MB HEIGHT DIFFERENCE
1200
1160
1120
1080
1040
1000
960
920
880
840
800
+4
+2
T 0
-2
-4
-40
-30
-20
-10
0
10
20
30
40
50
60
70
DAY

Fig 3


LONG 0-355
SUMMER
LAT 20-55
DAY 0 ≥ 1.0
— = MEAN HEIGHT
— = 21 DAY CONTINUUM
X = STUDENT'S T
700 MB HEIGHT DIFFERENCE
400
440
480
520
560
600
640
680
720
760
800
+4
+2
T 0
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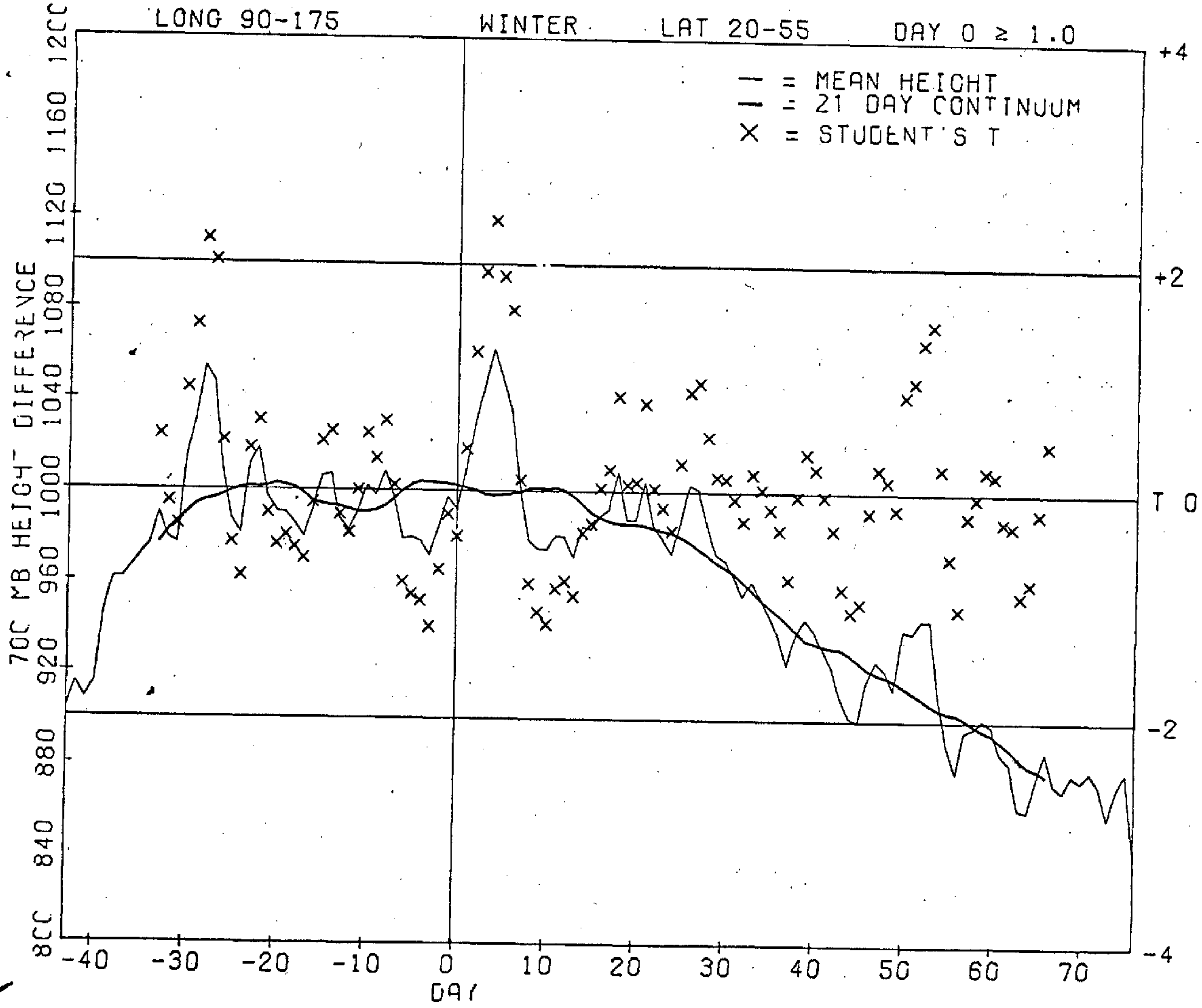
10
20
30
40
50
60
70
DAY

Fig 4



LONG 90-175
WINTER
LAT 20-55
DAY 0 ≥ 1.0
— = MEAN HEIGHT
— = 21 DAY CONTINUUM
X = STUDENT'S T
700 MB HEIGHT DIFFERENCE
1200
1160
1120
1080
1040
1000
960
920
880
840
800
+4
+2
T 0
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20
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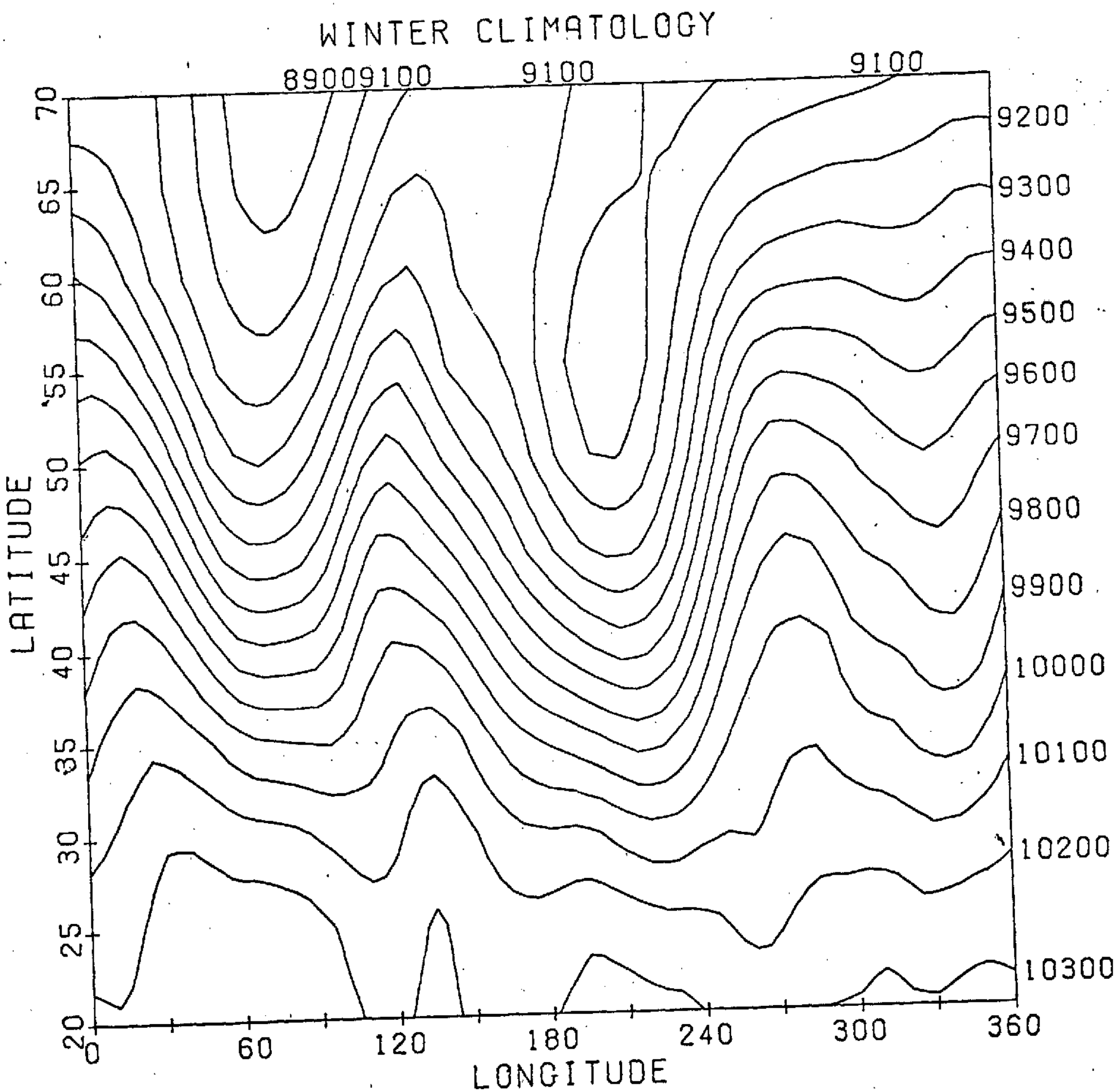
40
50
60
70
DAY

Fig 5



WINTER CLIMATOLOGY
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9100
9100
9200
9300
9400
9500
9600
9700
9800
9900
10000
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10200
10300
LATITUDE
70
65
60
55
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35
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240
300
360
LONGITUDE

Fig 6 ~~Fig 3~~

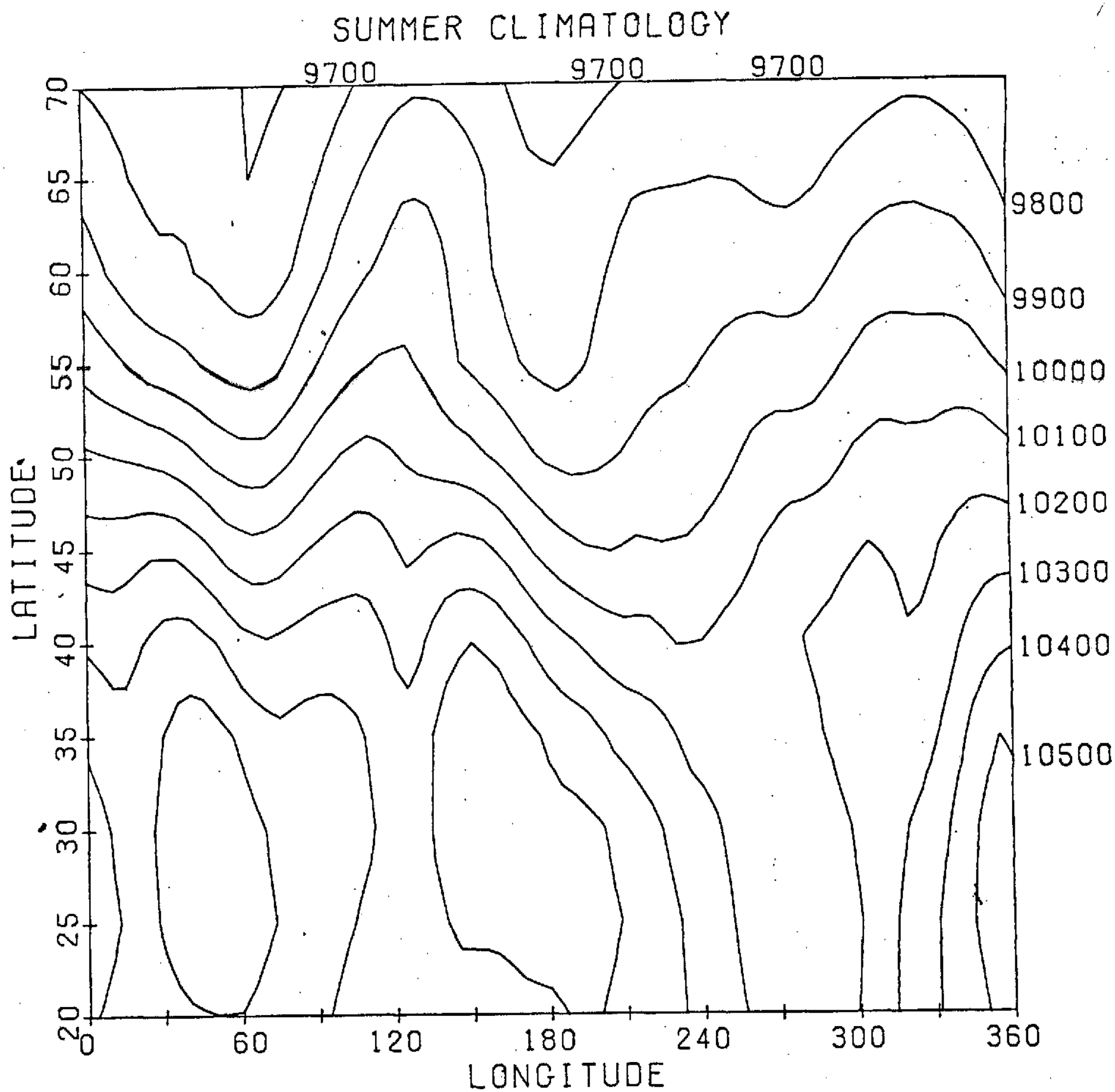
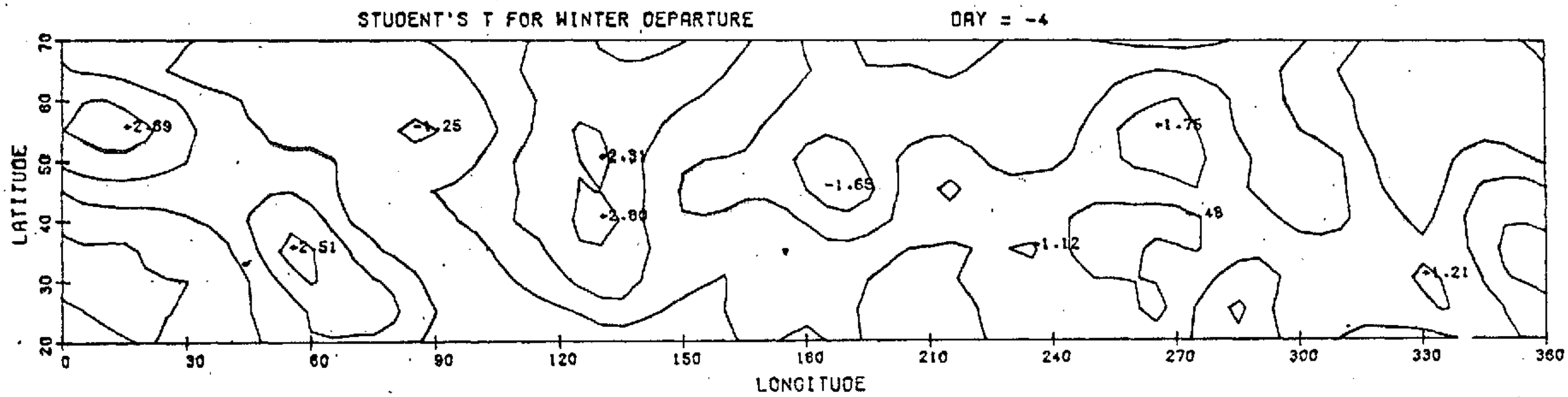


Fig 7 ~~Fig 4~~

No. 400

RECORDING CHARTS GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK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50
40
30
20
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90
120
150
180
210
240
270
300
330
360
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+2.31
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+2.51
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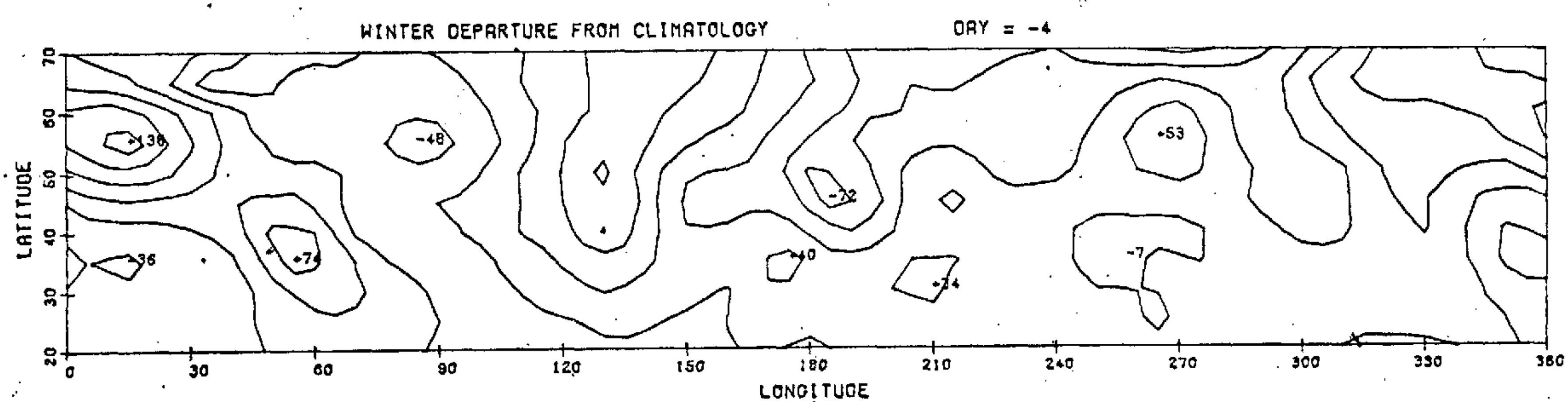
48
+1.12
+1.21


WINTER DEPARTURE FROM CLIMATOLOGY
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LONGITUDE
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60
50
40
30
20
0
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60
90
120
150
180
210
240
270
300
330
360
+138
-48
+53
-72
+36
+74
+40
+24
-7

~~Figure~~

Fig 8

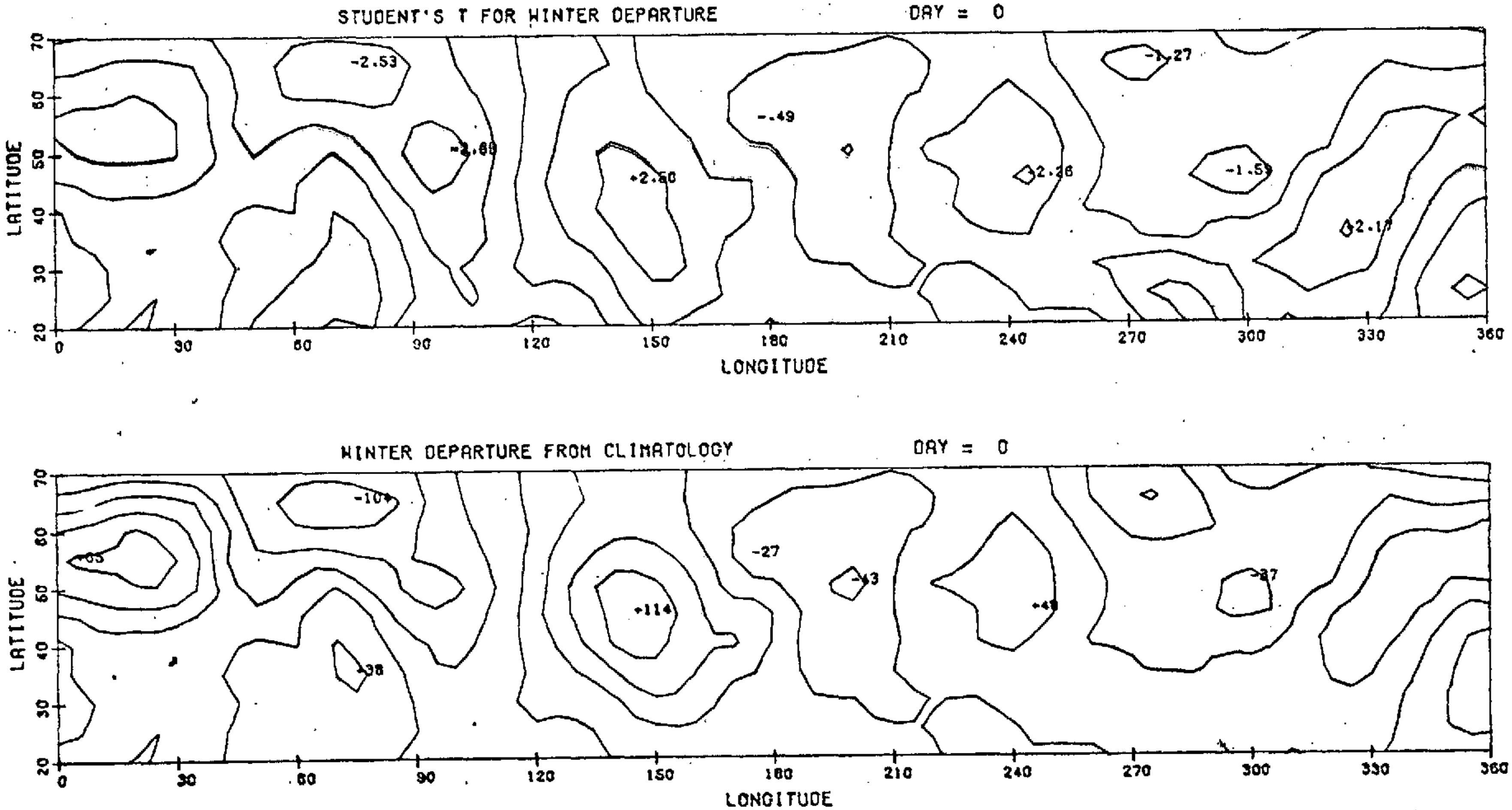
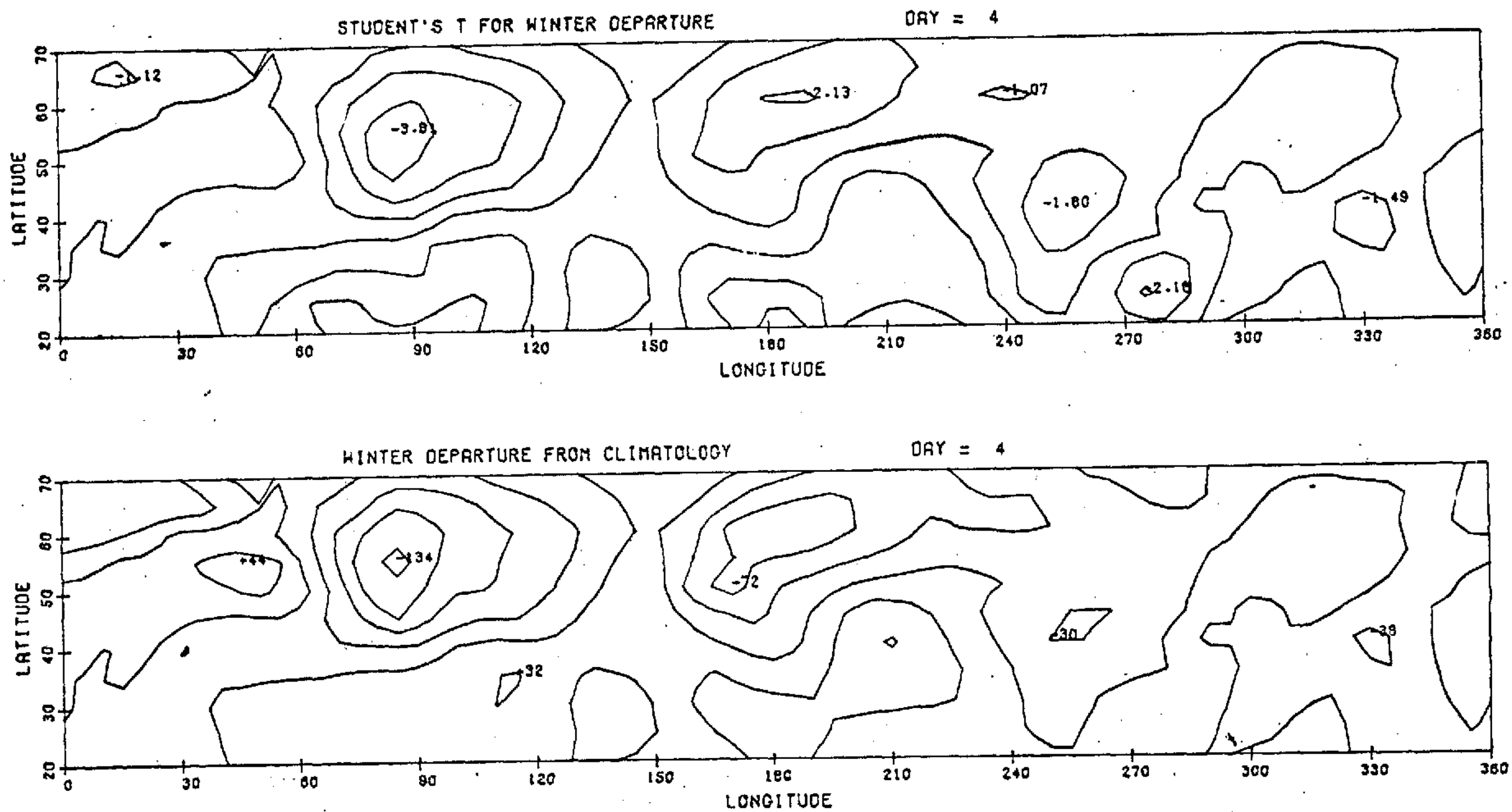

STUDENT'S T FOR WINTER DEPARTURE
DAY = 0
LATITUDE
LONGITUDE
-2.53
-1.27
-.49
+2.50
-1.53
WINTER DEPARTURE FROM CLIMATOLOGY
DAY = 0
LATITUDE
LONGITUDE
-27
+114
+38

Fig 9


STUDENT'S T FOR WINTER DEPARTURE
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LATITUDE
LONGITUDE
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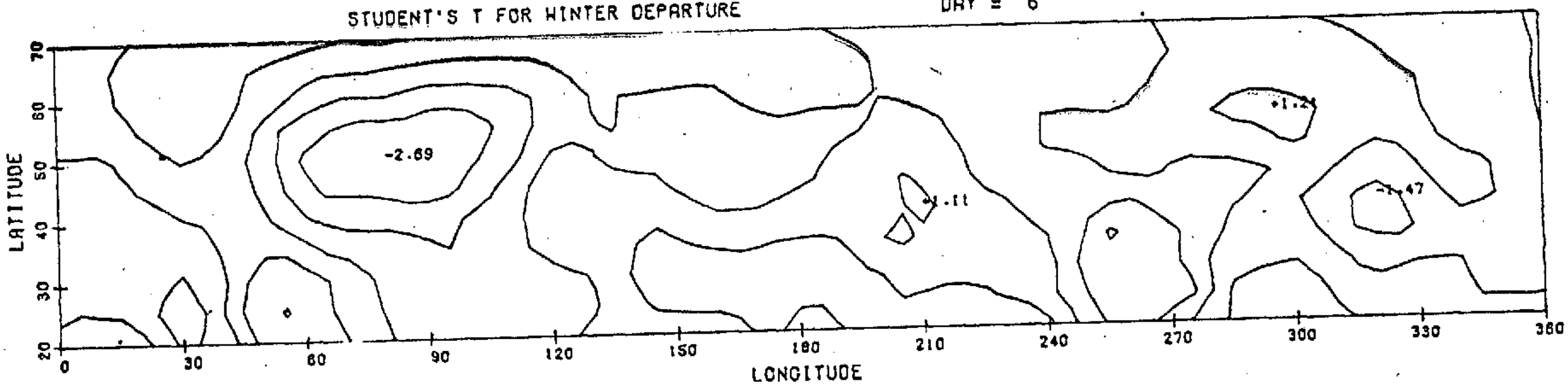
-2.13
-1.07
-1.80
-1.49
WINTER DEPARTURE FROM CLIMATOLOGY
DAY = 4
LATITUDE
LONGITUDE
-134
-72
+32
30

Fig 10

STUDENT'S T FOR WINTER DEPARTURE DAY = 6



WINTER DEPARTURE FROM CLIMATOLOGY DAY = 6

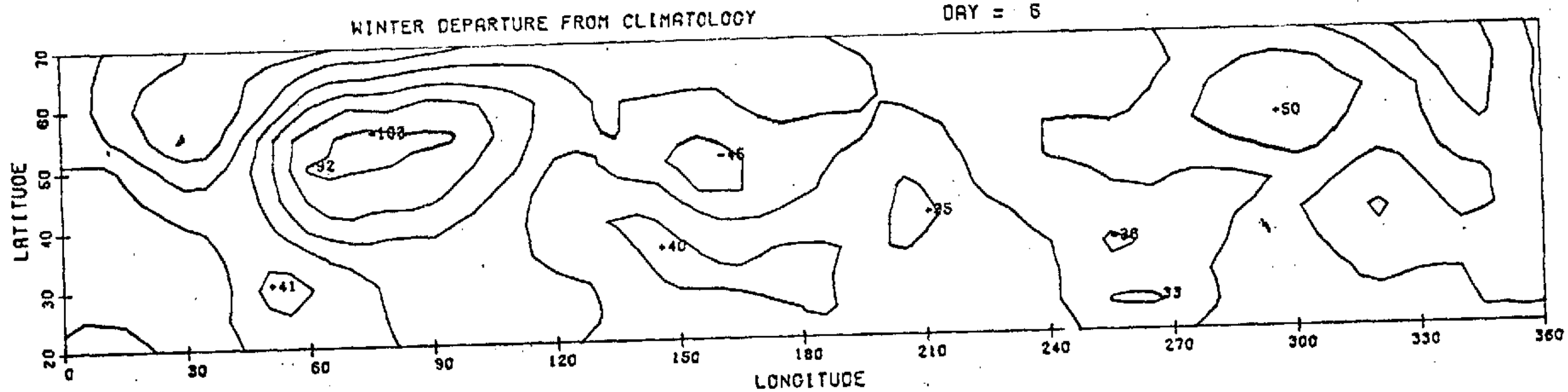
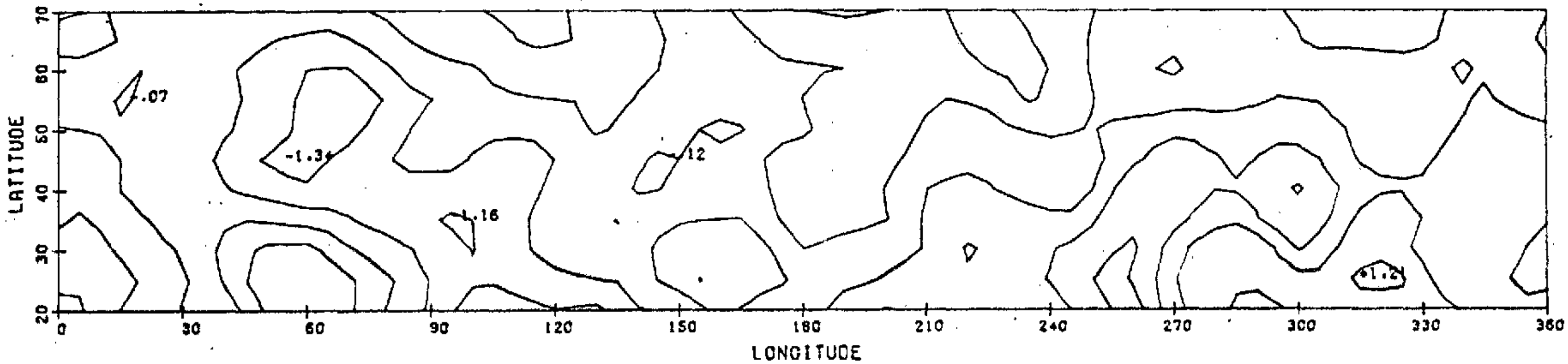


Fig 11

STUDENT'S T FOR WINTER DEPARTURE DAY = 8



WINTER DEPARTURE FROM CLIMATOLOGY DAY = 8

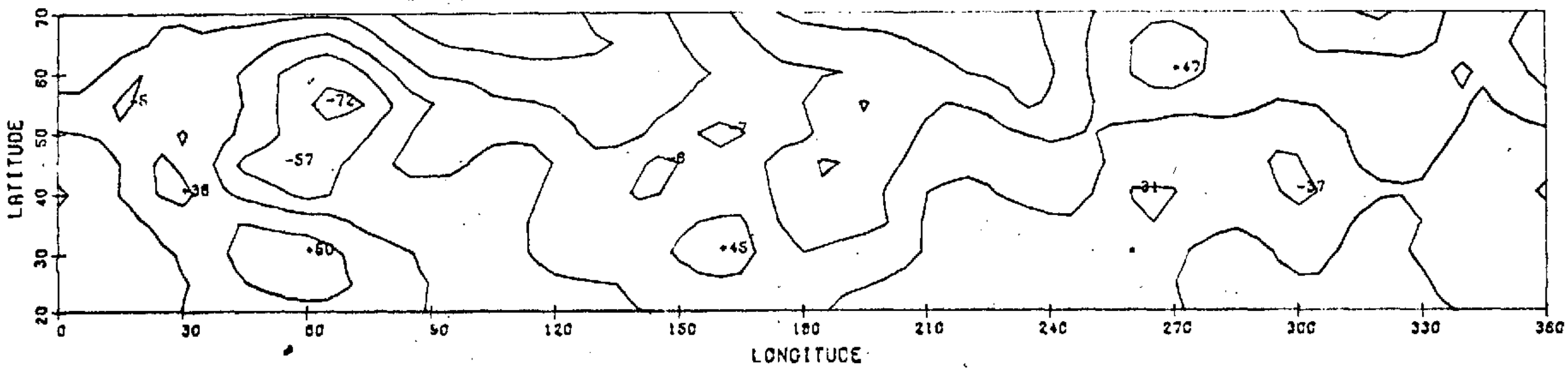
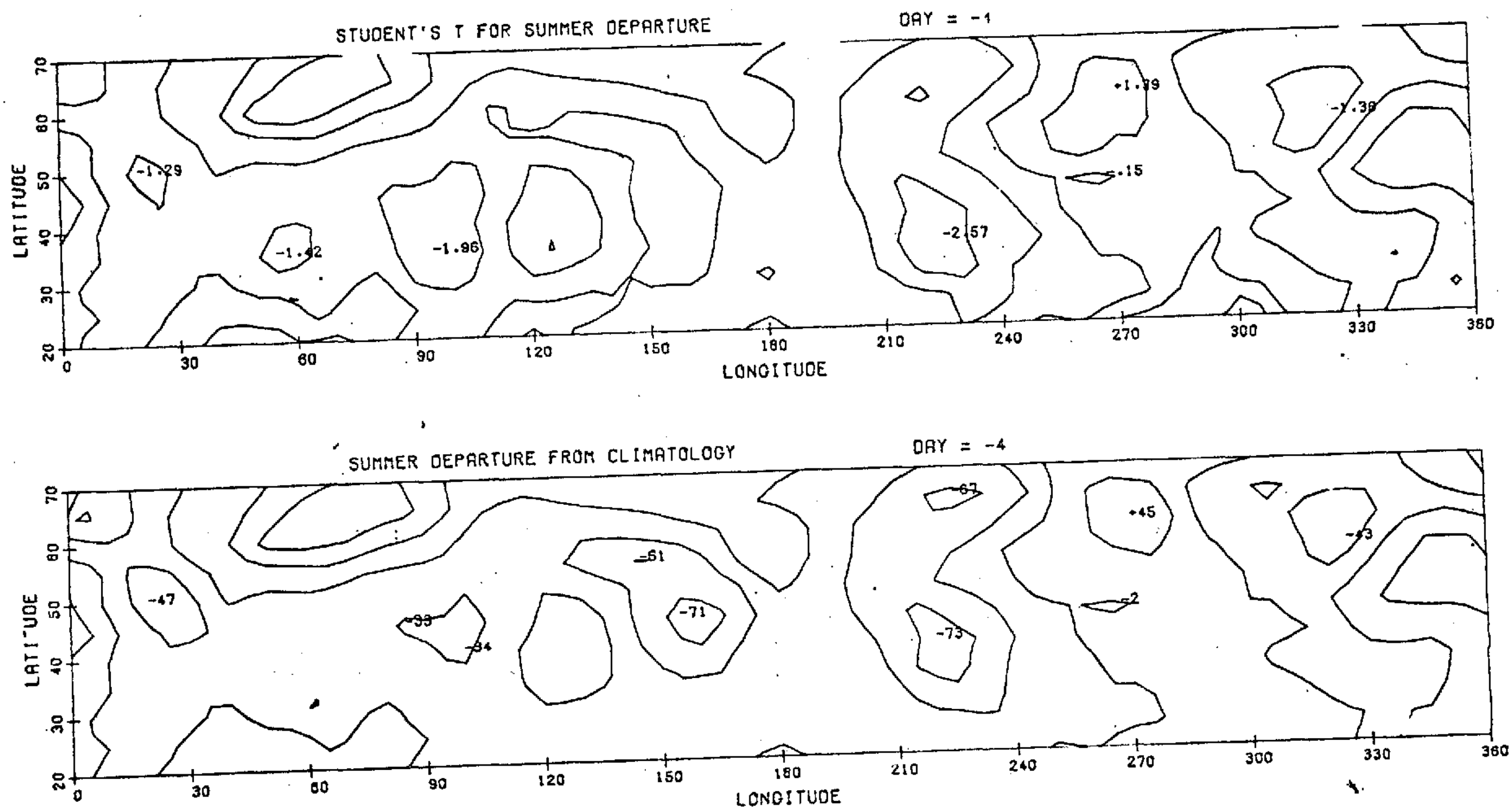


Fig 12



RECORDING CHARTS GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK

No. 400

Fig 13

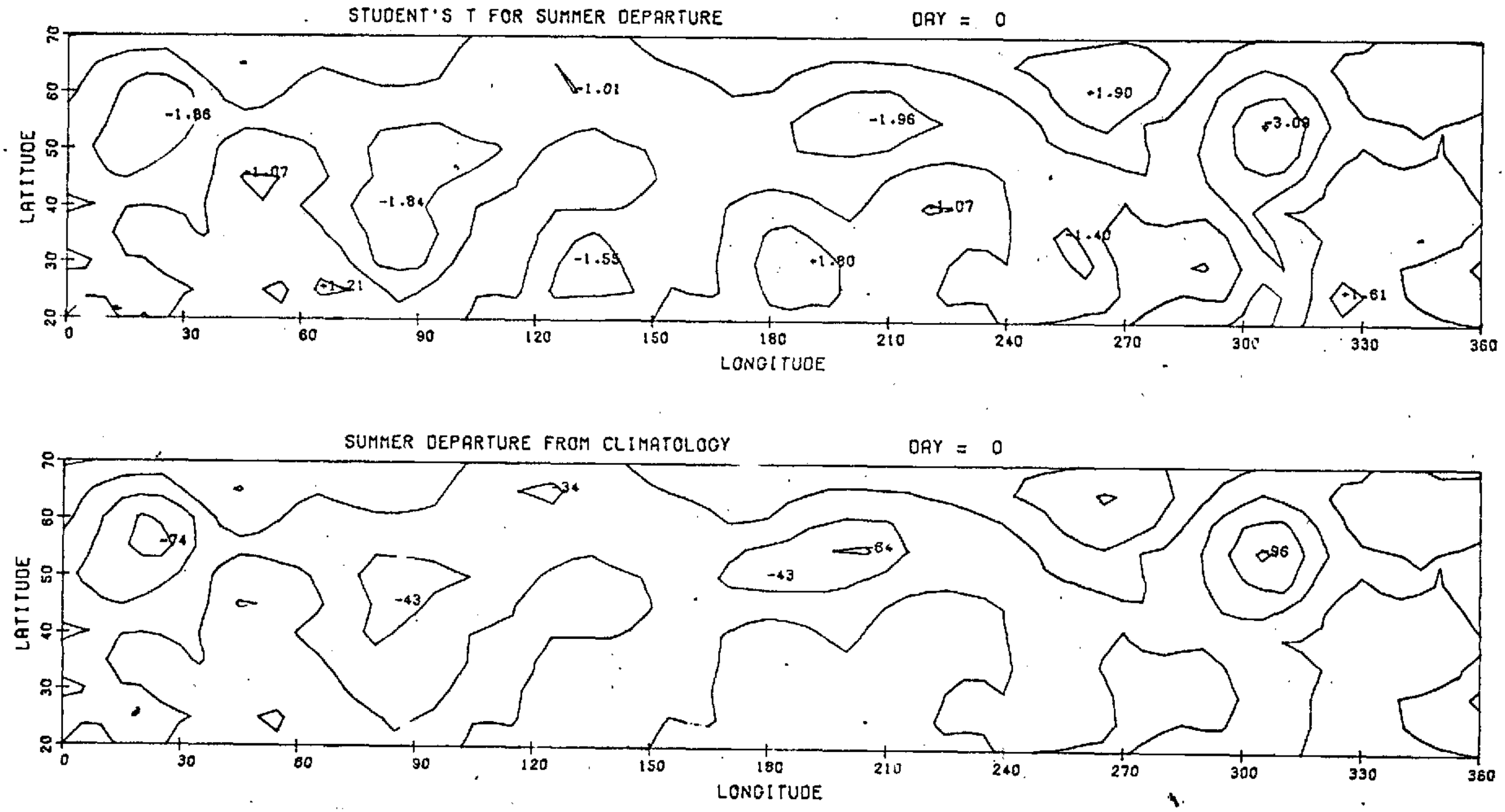
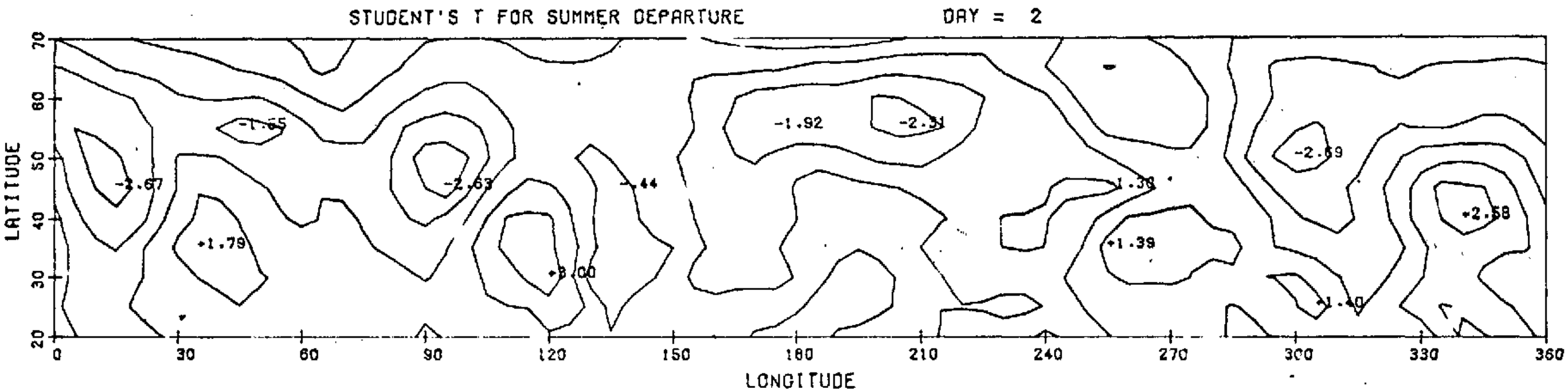

STUDENT'S T FOR SUMMER DEPARTURE
DAY = 0
LATITUDE
LONGITUDE
-1.86
-1.01
-1.96
+1.90
+3.09
+1.07
-1.84
+1.07
+1.40
-1.55
+1.80
+1.21
+1.61
SUMMER DEPARTURE FROM CLIMATOLOGY
DAY = 0
LATITUDE
LONGITUDE
-74
34
64
-43
-43
96

Fig 14


STUDENT'S T FOR SUMMER DEPARTURE DAY = 2
LATITUDE
LONGITUDE
-1.65
-2.67
+1.79
-2.63
+3.00
-.44
-1.92
-2.31
-1.38
+1.39
-2.69
+2.58
+1.40

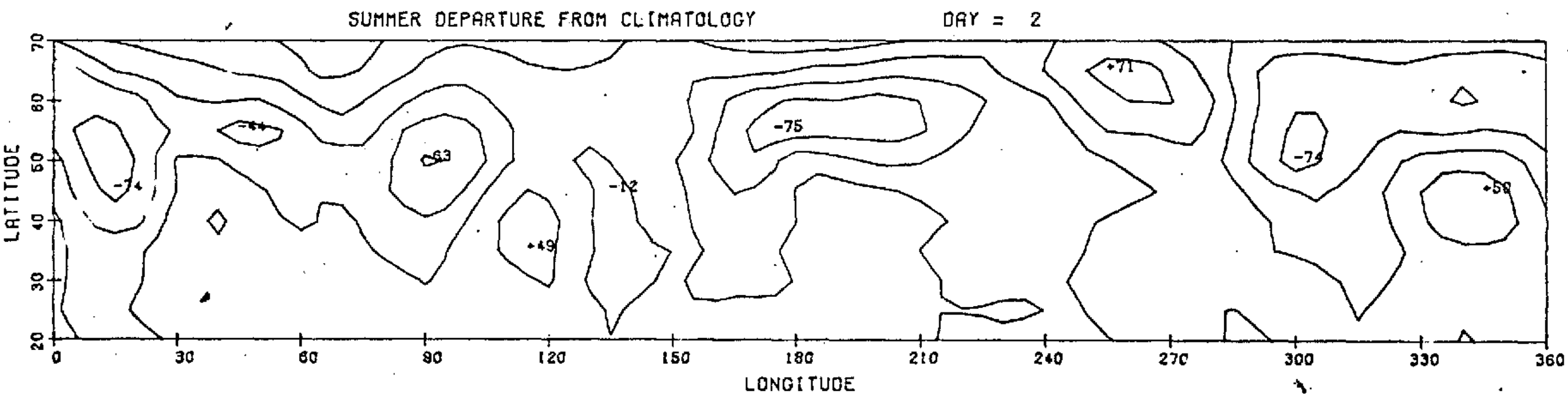
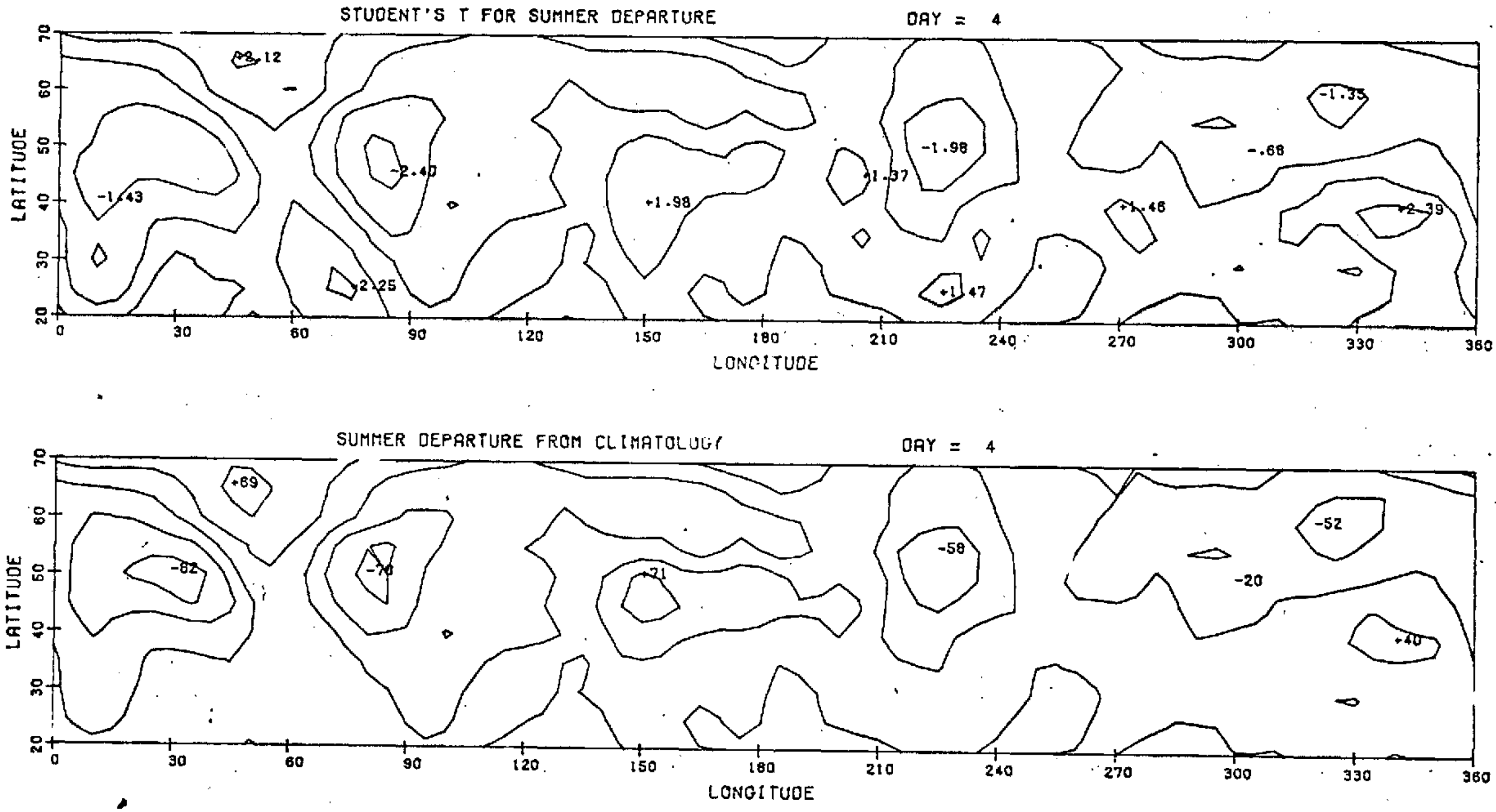
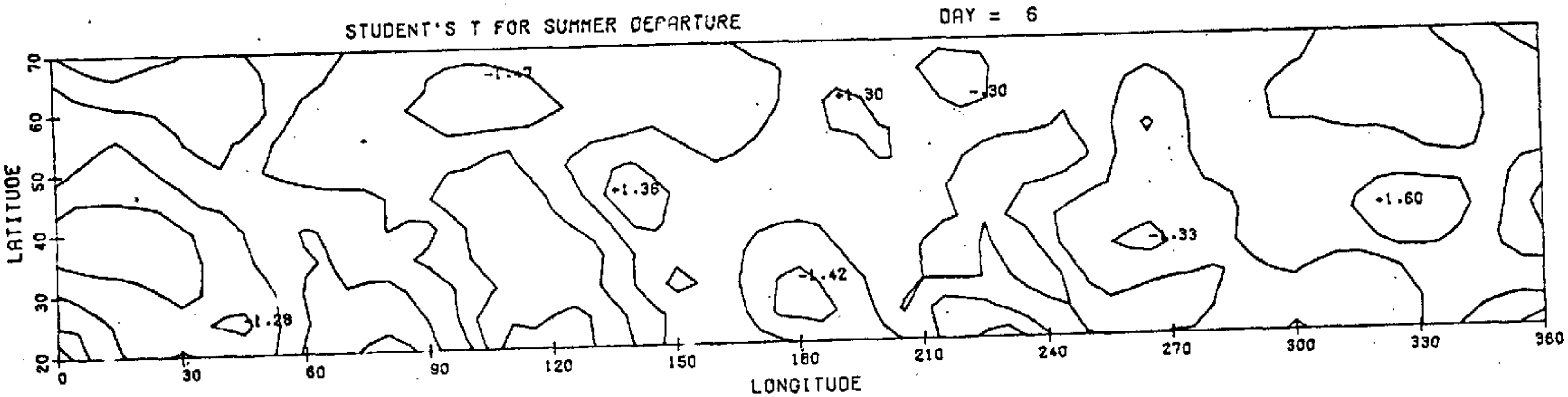

SUMMER DEPARTURE FROM CLIMATOLOGY DAY = 2
LATITUDE
LONGITUDE
-.44
-.74
-.63
+.49
-.12
-.75
+.71
-.74
+.50

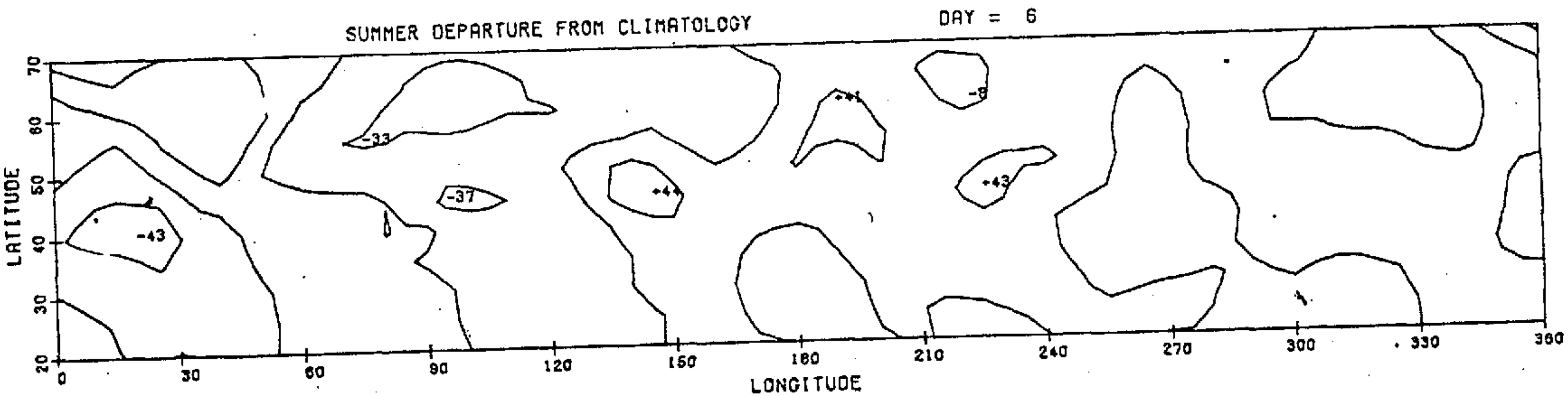
Fig 15


STUDENT'S T FOR SUMMER DEPARTURE
DAY = 4
LATITUDE
LONGITUDE
SUMMER DEPARTURE FROM CLIMATOLOGY
DAY = 4
LATITUDE
LONGITUDE

No. 400

Fig 16





Figure

Fig 17

No. 400